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SOLICO/LOTHECO
New Combined Cycle With Integrated Low Temperature Heat or Solar Heat

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Introduction

- **Goals of technological concepts concerning power generation**

  High efficiencies,
  Improved environmental performance

- **Combined cycle applications**

  Improved efficiency
  Economic, ecological benefits

A further step towards this direction (improved overall efficiency and reduced pollutant emissions) are the research activities dealing with the improvement of gas turbine efficiency. Known related concepts are the HAT (humid air turbine) and the Cheng Cycle.

HAT and Cheng Cycle Concept

• **HAT concept**

Water is injected into the combustion air, and part of the fuel chemical energy is used to evaporate and overheat the injected water.

• **Cheng cycle concept**

Overheated steam from a heat recovery boiler is injected into the combustion air

Through the injection the medium flow, which expands in the gas turbine, increases and causes a greater power output. Both concepts make use of high temperature energy for the evaporation and overheating of the injected water.

SOLICO- or LOTHECO Unit

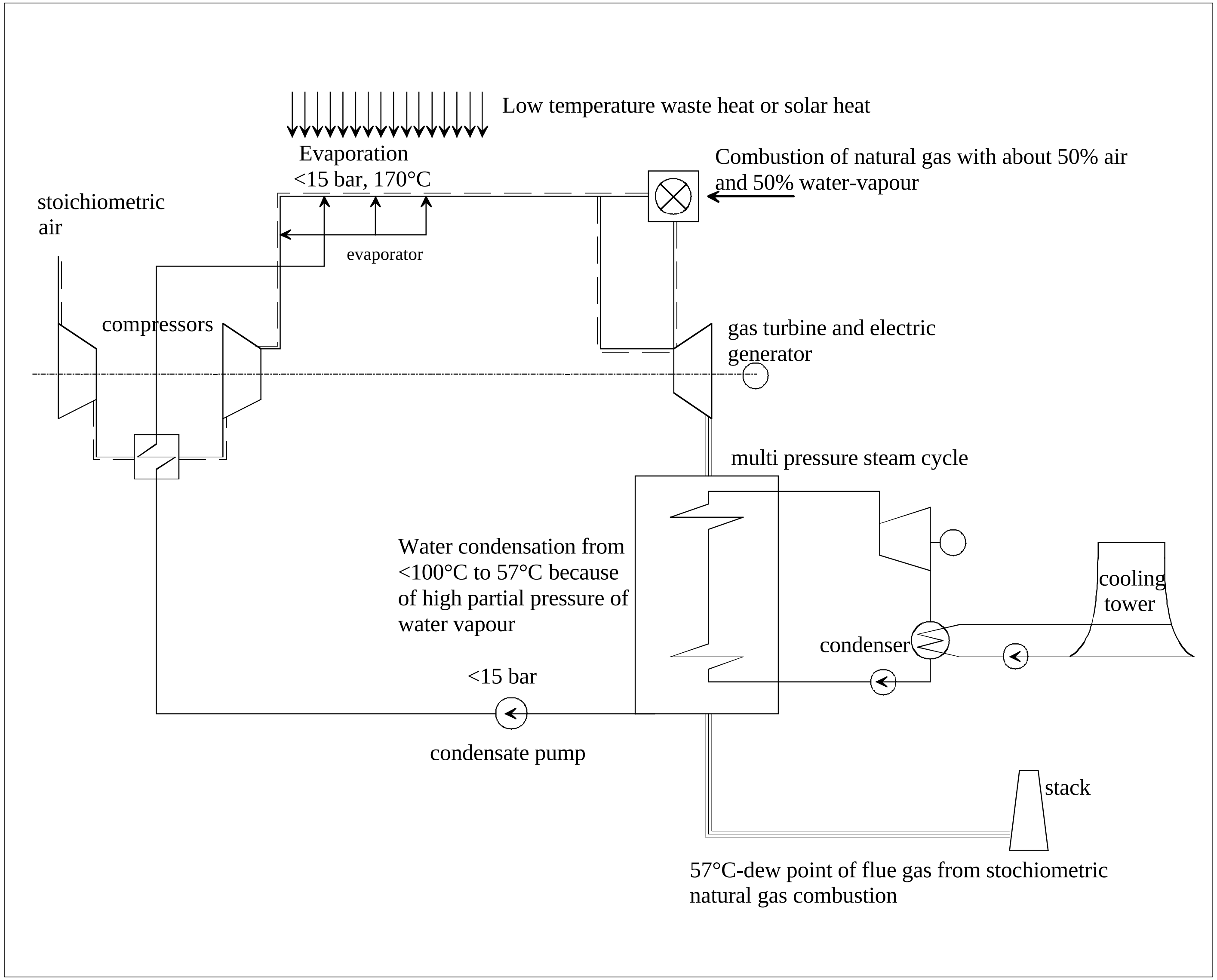
Innovations of the presented concept:

- The evaporation of the injected water takes place at partial pressure and therefore low temperature heat* can be used,

- In the heat recovery boiler steam is produced for a steam turbine and the part of the water-vapour content of the flue gas representing the injected water is condensed, cleaned and reused for injection.

***Possible energy sources could be various waste industrial heat sources or solar heat**

Simplified Schema of the Proposed Unit



Advantages of the Novel Combined Cycle

- The compression of only stoichiometric airflow leads to reduced compressor's power in comparison with conventional Combined Cycles
- The temperatures in the evaporator are very low because the injected water is evaporated at partial pressure i.e. from below 1 bar to about 7 bar; that means less than 100°C to about 170°C
- the heat transfer rate is very high in the evaporator because the heat transfer is enhanced by the water evaporation; phase change from droplets/air mixture to vapour/air mixture
- Very low NOx-emissions due to high water vapour content in the combustion air and low combustion temperatures
- If necessary the cycle could be operated as conventional combined cycle, using an additional compressor and matching bypasses, in case the waste heat is interrupted or during night when using solar heat.

Efficiency of LOTHECO- or SOLICO Unit

- **ENBIPRO (Energy-Balance-Program)**

The calculations of the proposed Cycle's efficiency were based on the computational software code ENBIPRO, which is developed during the last years by IWBT.

The basic problem

the existing version had to be modified to be able to calculate the water evaporation and the flue gas condensation, with the adaptation of a suitable software code for humid air.

Input parameters of ENBIPRO

The major parameters used as input for the estimation of the overall efficiency are divided into two categories:

- Input data of the gas turbine cycle (namely):

- air surplus λ for the combustion,
- fuel mass rate m_B,
- gas turbine pressure ratio,
- pressure drop after each evaporator (calculated only for SOLICO-unit),
- temperature, pressure and mass flow of the water injections and
- chemical composition of the fuel and combustion air

- Input data of the steam cycle:

- input or output temperatures of each component,
- mass flow of each steam cycle, and all divisions and
- pressure ratio of the pumps and steam turbines

Output power and efficiency of LOTHECO- or SOLICO-Unit

Output power and efficiencies	**Units**	**Value**
Output of the HP-steam turbine	MW	0,648
Output of the MP-steam turbine	MW	1,383
Output of the LP-steam turbine	MW	0,658
Gross output power of the Steam Cycle	MW_{th}	2,690
Efficiency of the Steam Cycle related to the natural gas consumption	%	27,76
Net output power of the gas turbine	MW	4,220
Efficiency of the gas turbine related to the natural gas consumption	%	43,76
Net output power of the Unit	MW	6,881
Fuel heat rate	MW_{th}	9,642
Low temperature waste heat or solar heat input	MW_{th}	10,450
Overall efficiency related to the natural gas consumption	%	71,52
Overall efficiency related to the natural gas consumption and low temperature or solar heat input	%	34,32

Exergy analysis of the LOTHECO- or SOLICO unit

According to exergy balance, the total amount of exergy supplied to system through materials flows ($\Sigma(E\xi_\varepsilon)$), ηεατ ($E\xi_\Theta$) ανδ ενεργψ τρανσφερ ($E\xi_\Omega$), ισ εθυαλ το τηε τοταλ αμουντ οφ εξεργψ οφ τηε φλοωσ εξιτινγ τηε σψστεμ ($\Sigma(E\xi_\alpha)$) πλυσ τηε εξεργψ δεστρυχτιον ($E\xi_\Delta$) ανδ τηε εξεργψ λοσσ ($E\xi_\Lambda$).

$$Ex_Q + Ex_W + \Sigma(E\xi_\varepsilon) = \Sigma(E\xi_\alpha) + E\xi_\Lambda + E\xi_\Delta$$

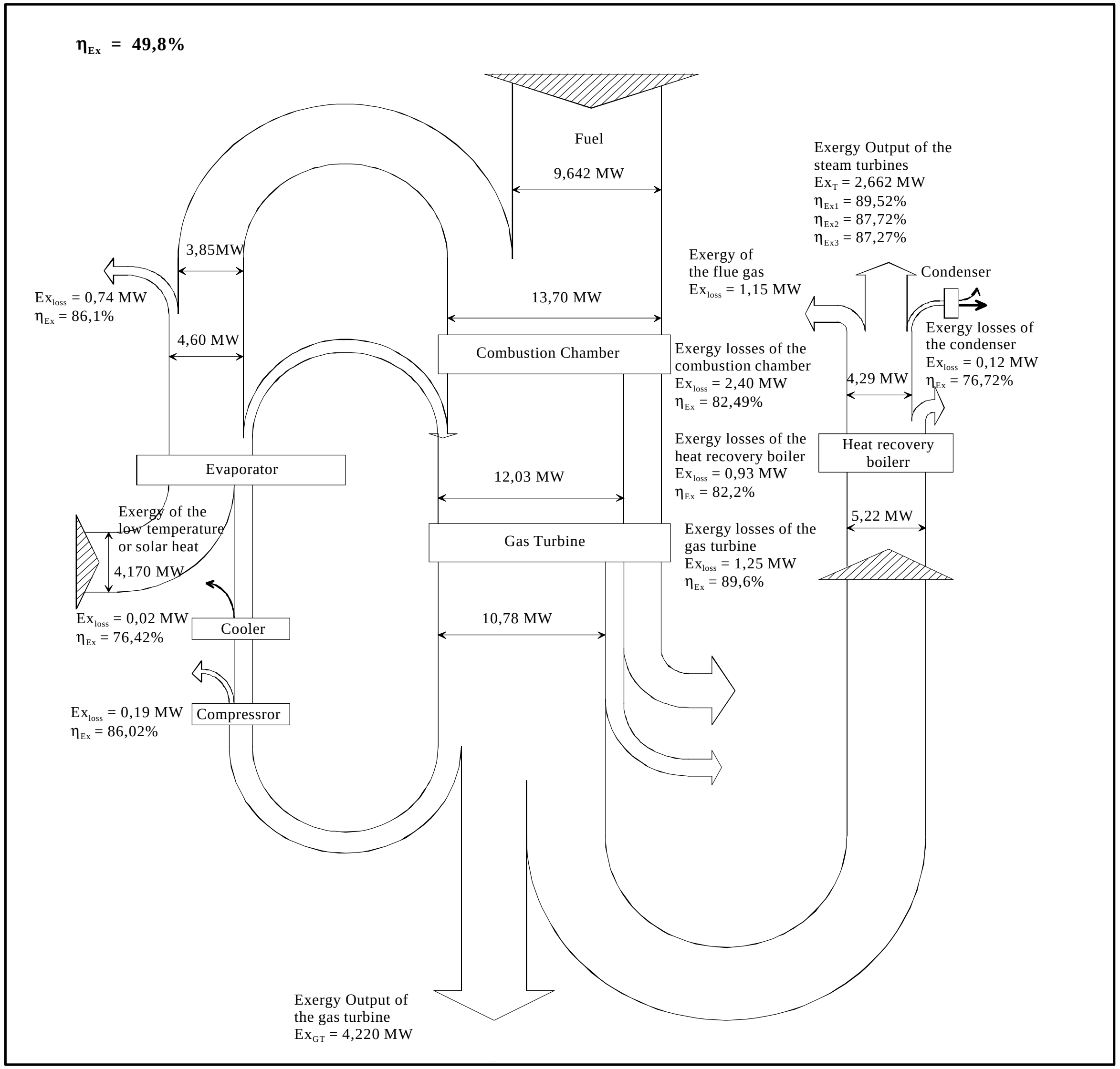
Φορ εϖερψ τηερμοδψναμιχ σψστεμ ωε χαν δεφινε α φυελ ανδ α προδυχτ τερμ. Τηυσ τηε εξεργψ βαλανχε βεχομεσ:

$$E\xi_\Phi = E\xi_\Pi + E\xi_\Lambda + E\xi_\Delta$$

Αχχορδινγ το τηε δεφινιτιον αβοϖε τηε εξεργετιχ εφφιχιενχψ χαν βε δεφινεδ ασ τηε ρατιο βετωεεν τηε εξεργψ οφ τηε προδυχτ ανδ τηε εξεργψ οφ τηε φυελ .

$$\eta_{E\xi} = E\xi_\Pi / E\xi_\Phi = 1 \quad ((E\xi_\Lambda + E\xi_\Delta) / E\xi_\Phi)$$

Exergy flow diagram



Economic Analysis of the new Combined Cycle

The economic analysis deals with the future cost of electricity (COE) of the new Combined Cycle and its comparison with the equivalent cost of existing natural gas fired Combined Cycle. The following diagrams high-light the results of this analysis, which includes the following parameters associated with the cost of electricity,

- Operation hours per year - B_h(hr)
- Fuel costs and their future perspectives - b(DM/kWh_{Gas})
- Specific investment costs - K(DM/kW)

The cost comparison of those two units, for a certain rate of interest, life span and efficiency, gives the amount of money which could be invested (for the evaporator, polishing plant etc.) and which could be earned from the fuel savings.

Total cost criterion

Alternative units have different costs, both fixed and variable. A total-cost-criterion is required, which converts the fixed costs to equivalent variable costs and expresses the total in DM/kWh.

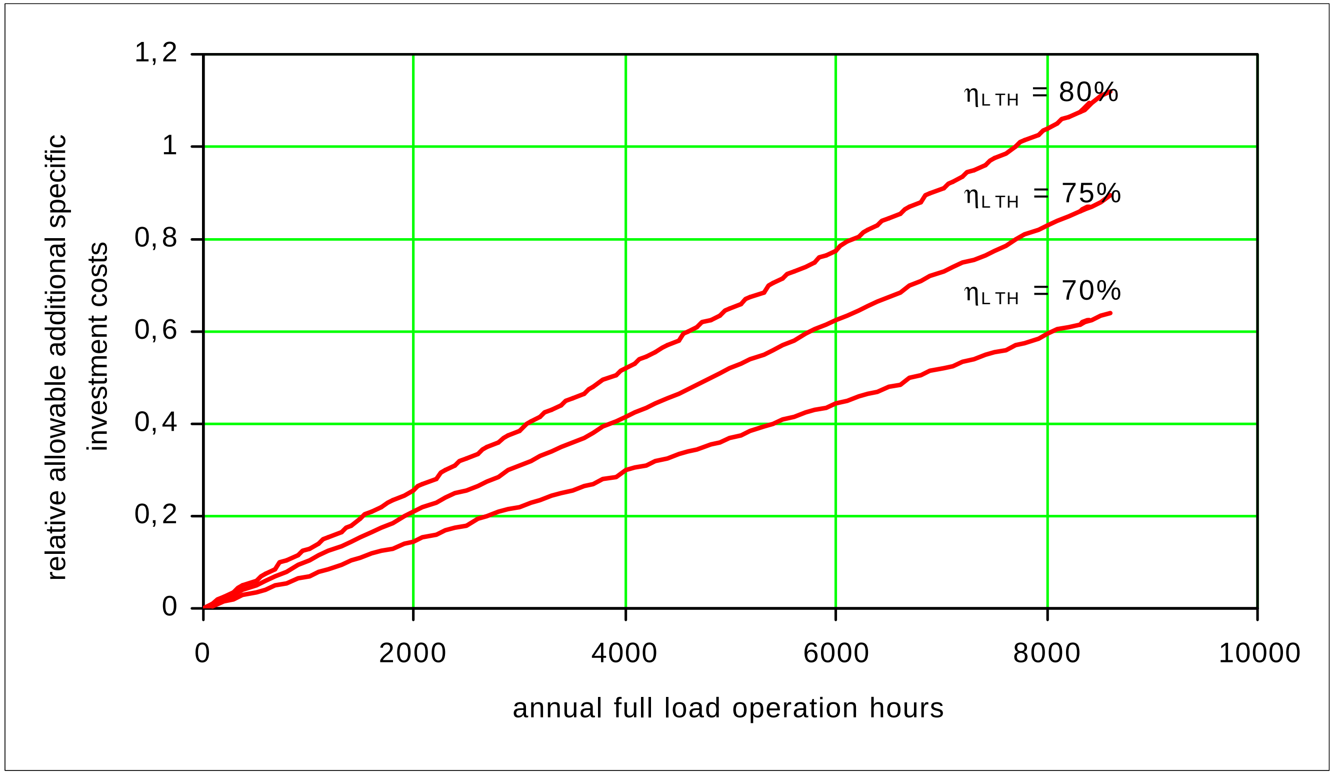
Criterion of cost of electricity (COE) k_e

Assuming that the costs of electricity are the same and further that the annual full load hours, the annuity expressed per year and the fuel prices are also the same for both plants, the allowed specific investment cost surplus of the LOTHECO unit is given by:

$$\frac{K_{LTH} - K_{GuD}}{K_{GuD}} = \frac{B_h b}{K_{GuD} \cdot \text{á}} \cdot \frac{1}{\text{ç}_{GuD}} \cdot \left(1 - \frac{\text{ç}_{GuD}}{\text{ç}_{LTH}}\right)$$

a) Operation hours B_h

For the parameters K_{GuD} = 800DM/kW and η_{GuD} = 60% the relative allowed additional specific investment costs depend on the full load operational hours and for a variety of efficiencies n_{LTH}, annuities and fuel prices are:



For b = 0,025 DM/kWh$_{Gas}$ and a = 0,1 yr^{-1}

The relative allowable additional specific investment costs dependant by the fuel prices b and the annuity α

- b (DM/KWh) increases
- The term $\frac{K_{LTH} - K_{GuD}}{K_{GuD}}$ increases
- α (yr^{-1}) decreases
- The term $\frac{K_{LTH} - K_{GuD}}{K_{GuD}}$ increases
- b (DM/KWh) decreases
- The term $\frac{K_{LTH} - K_{GuD}}{K_{GuD}}$ decreases

Discussion and Conclusions

Guidelines for the development of new processes for thermal power plants are:

- Saving of the resources,
- Reduction of the environmental pollution

Both goals can be accomplished by increasing the efficiency through the integration of low quality energy sources in conventional units.

The novel Combined Cycle, described by the LOTHECO or SOLICO project, represents a modern, efficient and economic way to integrate these energy resources in conventional plants for electric power production. In the future the implementation of the renewable sources and of sources of low-quality energy will offer new possibilities in conventional plants to produce electricity at considerably lower costs in comparison with the techniques developed until today